A FLOW VISUALIZATION STUDY OF FREE ROLLING CRUCIFORM FINS IN CROSS FLOW

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November 1973

UNCLASSIFIED
Security Classification

AD-771035

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)*

Naval Weapons Laboratory
Dahlgren, Virginia 22448

2a. REPORT SECURITY CLASSIFICATION

UNCLASSIFIED

2b. GROUP

3. REPORT TITLE

A FLOW VISUALIZATION STUDY OF FREE ROLLING CRUCIFORM FINS IN CROSS FLOW

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

5. AUTHOR(S) *(First name, middle initial, last name)*

P. Daniels

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
November 1973		

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO.	NWL TR-3053
c.	9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*
d.	

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY

13. ABSTRACT

A smoke flow visualization study was conducted at subsonic speeds which showed that roll speed-up can be produced by vortices shed from fins alone. This vortex shedding is displayed at large and small roll rates.

DD FORM 1 NOV 68 1473 (PAGE 1)
S/N 0102-014-6700

UNCLASSIFIED

NWL Technical Report No. TR-3053
November 1973

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FOREWORD

This report describes work directed toward alleviating dynamic stability problems of finned missiles.

Acknowledgement is due Dr. T. A. Clare who conducted the experiment in accordance with NWL requirements while he was a graduate student at the University of Notre Dame.

This work was performed under AIRTASK A3200000/009B/3F32320000.

This report was reviewed by R. D. Cuddy, Head of the Aeroballistics Division.

Released by:

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Head, Warfare Analysis Department

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1. INTRODUCTION

Air launched weapons with solid cruciform fins are particularly difficult to stabilize because of the highly non-linear character of their rolling torques with angle of attack, roll angle, and roll rate.[1,2] At high angles of attack, the cruciform finned missile will develop large roll rate in either the clockwise or counter-clockwise directions, even against the fin cant. This phenomenon is known as roll speed-up.

Roll speed-up is not well understood. However, it is known to be associated with vortices shed from the fins and it is the purpose of this paper to display these vortices.

II. EXPERIMENTAL EVIDENCE

There is considerable evidence[3,4,5,6,7] to show that roll speed-up is associated with vortex shedding from the fins. The Naval Weapons Laboratory recently requested the Aerospace Department of the University of Notre Dame to conduct a flow visualization study of cruciform fins in cross flow in order to provide data for additional analysis.

The test specimen is presented in Figure 1. The fins had a span of approximately six inches and were free to roll. The configuration was mounted on the floor (90 degrees to the flow) of an induction type, low turbulence, subsonic wind tunnel. Smoke was emitted into the free stream while the model was held stationary at an initial roll orientation angle (γ) approximately equal to 45 degrees. The model was released and developed divergent roll oscillations which resulted in "break-out" and "speed-up." Motion pictures were taken with a high speed camera. Some results of the test are presented in Figure 2. It should be noted that the model could spin equally well in either direction. However, only clockwise spin (as viewed from above) is shown in Figure 2.

Figure 2A shows the first 90 degrees of rotation that the fins make during the first complete rotation (motion changes from oscillation to circulation). The average rolling velocity (γ) is three rev./sec. Figure 2B is the quasi-steady state roll which the fins eventually achieve. The average roll rate (γ) for this case is 11 rev./sec. In each case the shedding of a large vortex from the retreating fin is clearly shown. The streak lines in front of the model are drastically affected by large rolling velocity when the roll orientation angle (γ) is nearly zero degrees. However as γ approaches 45 degrees the flow fields appear to be more similar. The vortex develops at a smaller roll angle (γ = 15 degrees) at the low roll rate and the outer streak lines show much more velocity across the free stream at the high roll rate.

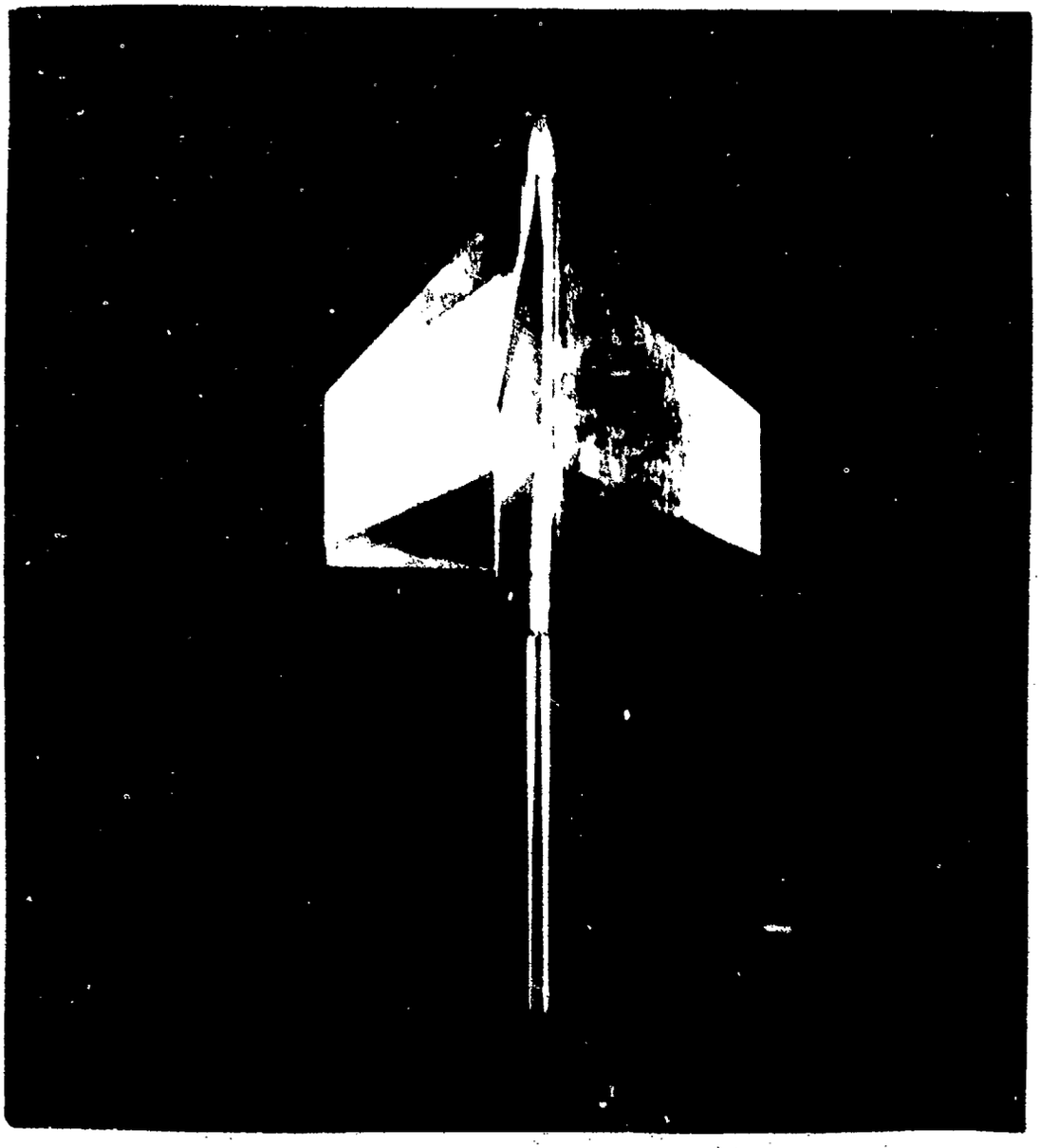
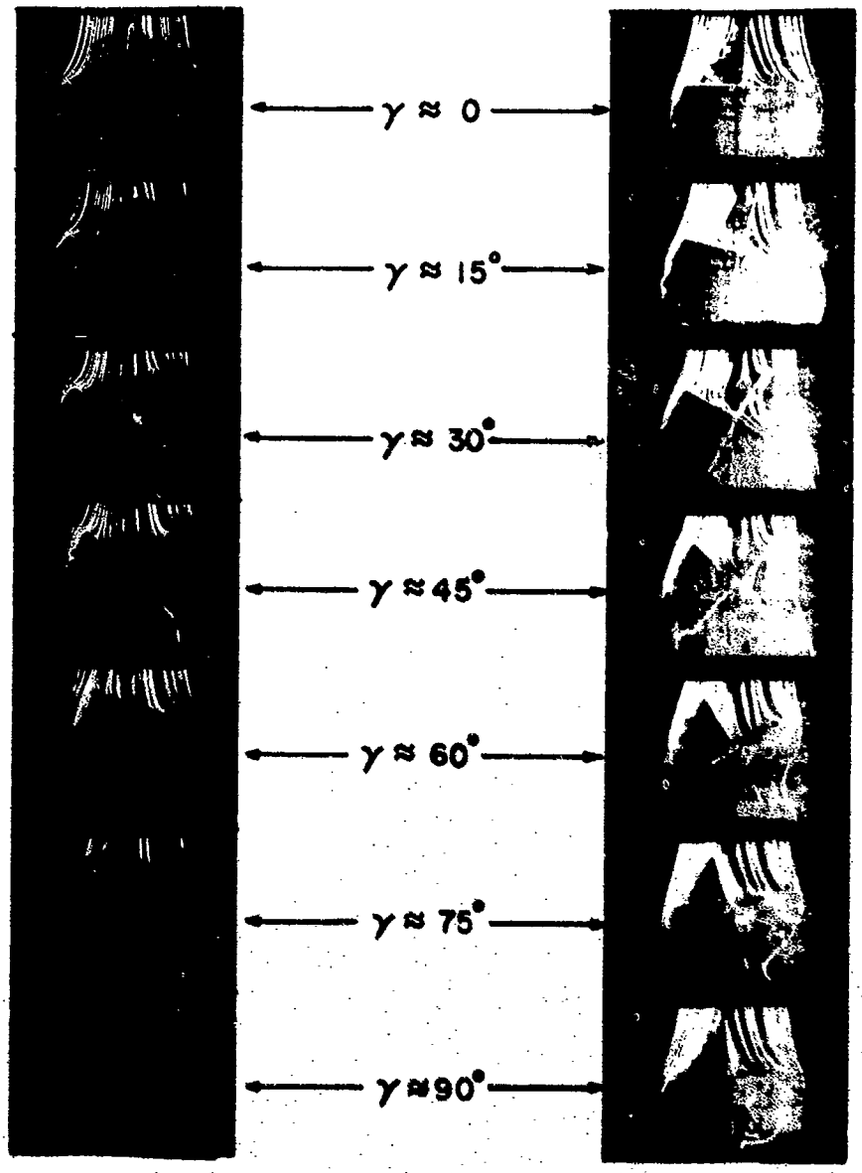


FIGURE 1

Conoform Fins Used in Flow
Visualization Study



A. FIRST 90 DEGREE ROTATION IN SPEED – UP. $\bar{\dot{\gamma}}$ ≈ 3 REV/SEC.

B. SPEED – UP ; QUASI – STEADY STATE SPIN. $\bar{\dot{\gamma}}$ ≈ 11 REV/SEC.

FIGURE 2

Flow Visualization of Cruciform Fins in Cross Flow. Free Steam Velocity ≈ 50 ft/sec

III. COMMENT

Many observers have conjectured that roll speed-up of finned missiles was produced by vortices shed from the body. It should be noted that the roll speed-up observed in this experiment was produced by flow over the tail alone, so that shed vortices from a body played no part whatsoever. (Roll speed-up for tail alone was first observed by Nicolaides.[4]) It should further be noted that the roll rate can be controlled by fin slots,[8] and it would be desirable to conduct smoke flow studies to find the effect of slots on the flow field.

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